Electro-Spark Deposited Coatings for Replacement of Chrome Electroplating (on Non-Line-of Sight Surfaces)

Cocoa Beach Briefing for HCAT Meeting

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PERFORMERS

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Richard Hays	**Naval Surface Warfare Center, Carderock – Naval Surface Technical Monitor**
Major Barnard Ghim	**Wright Patterson AFB – Air Force Technical Monitor**
Karl Tebeau	**U.S. Army Tank & Automotive Center – Army Technical Monitor**
Andrew Goetz	**Industrial Ecology Center – Task Administrator**

TECHNICAL OBJECTIVE

Develop an environmentally benign process, *Electro-Spark Deposition (ESD)*, that can apply superior protective coatings to non-line-of-sight and inside diameter surfaces.

TECHNICAL APPROACH

<u>Determine</u> relationships of key process parameters, deposition rate, and coating quality through recording of electronic wave forms, spark energy characteristics, metallographic characterization, and gravimetric analyses.

<u>Develop</u> sensors and controls to maintain optimum arc characteristics under varying conditions where visual monitoring cannot be performed (Non-Line-Of-Sight Surfaces)

TECHNICAL APPROACH

Select substrate materials and coating candidates representative of Tri-Service applications and needs

Coat test specimens and surfaces representative of Non-Line-Of-Sight geometries

Test coatings for corrosion, wear, fatigue

ACCOMPLISHMENTS

- **Selection of candidate coating materials completed**
- **Selection of substrate materials representative of Tri-Service needs completed**
- **Determined effect of wave form on coating quality**
- **High speed videography trials completed, characterization technique eliminated**
- **Development of force sensors and controls started**
- **Development of controls and algorithms to maintain optimum deposition parameters started**
- **Systematic characterization of parameters started, 287 specimens coated, evaluation in progress**
- **Nb Carbide Ni-Mo Electrode Shipped to PNNL**

ACCOMPLISHMENTS

CANDIDATE COATINGS SELECTED

■**Primary candidates**

- **WC-25TaC-13Co** - good wear-resistant carbide-base coating
- **Stellite 6** -Cobalt-base alloy, for surface build-up, wear, and corrosion

■**Secondary Candidates**

- **Chromium Carbide - 15Ni** - High temperature wear and corrosion
- **Nb Carbide -Ni-Mo** - High temperature wear
- **TiAl-TiB_2** - Tough, wear resistant

ACCOMPLISHMENTS

SUBSTRATE MATERIALS SELECTED

- **4340 Steel -** Chrome Nickel Molybdenum high Strength Steel Used throughout the DOD
- **Inconel 718-** Nickel Base High Strength Structural Alloy, Used in Turbine Engines
- **300 M Steel -** Torsion bars, Springs, Landing gears
- **PH13-8Mo Stainless Steel-** Precipitation Hardening Stainless Steel Representative
- **7075-T6 Aluminum-** Aircraft Structural Aluminum

ACCOMPLISHMENTS

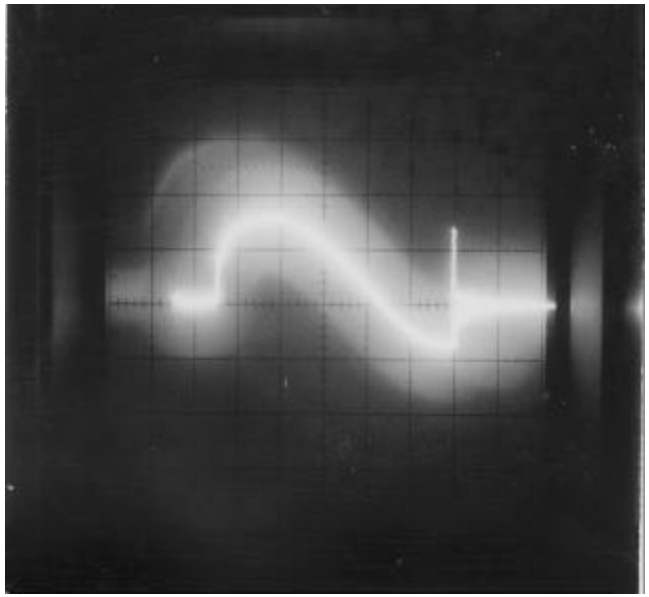
High Speed Videography Trials Completed

- Good results in other weld process characterizations
- State-of-the-art equipment used at EWI, but inadequate for arc conditions in ESD
- Videography eliminated as characterization technique

Wave Form Effects on Coating Quality

- Decreasing spark duration increases surface smoothness but decreases deposition rate at equal spark energies.

- Increasing spark duration increases Heat Affected Zone of sensitive substrates.



ACCOMPLISHMENTS

Process Parameter Optimization in Progress

- **287 specimens coated**
  - 4340 steel with tungsten carbide coating
  - 4340 steel with cobalt alloy (Stellite 6) coating

- **Characterization tests started**
  - metallography
  - gravimetric analysis
  - scanning electron microscopy
  - surface profilometry
  - atomic force microscopy
  - microhardness profiles

- **Special electrode compositions being fabricated**
  - Niobium carbide -Sent to PNNL 5 Dec
  - TiAl-TiB_2 (Titanium Aluminide-Titanium Di-Boride)

- **Regular Electrodes**
  - -Tungsten Carbide- 25%TaC-13%Co
  - Stellite 6

ESD PROCESS PARAMETERS

ELECTRODE & MOTION

- *Material*
  composition, density, micro-structure
- *Geometry*
- *Speed*
- *Contact Force*
- *Number of passes*
- *Overlap of passes*

ENVIRONMENT

- *Gas composition*
- *Flow rate*
- *Temperature*
- *Geometry of flow*

SUBSTRATE

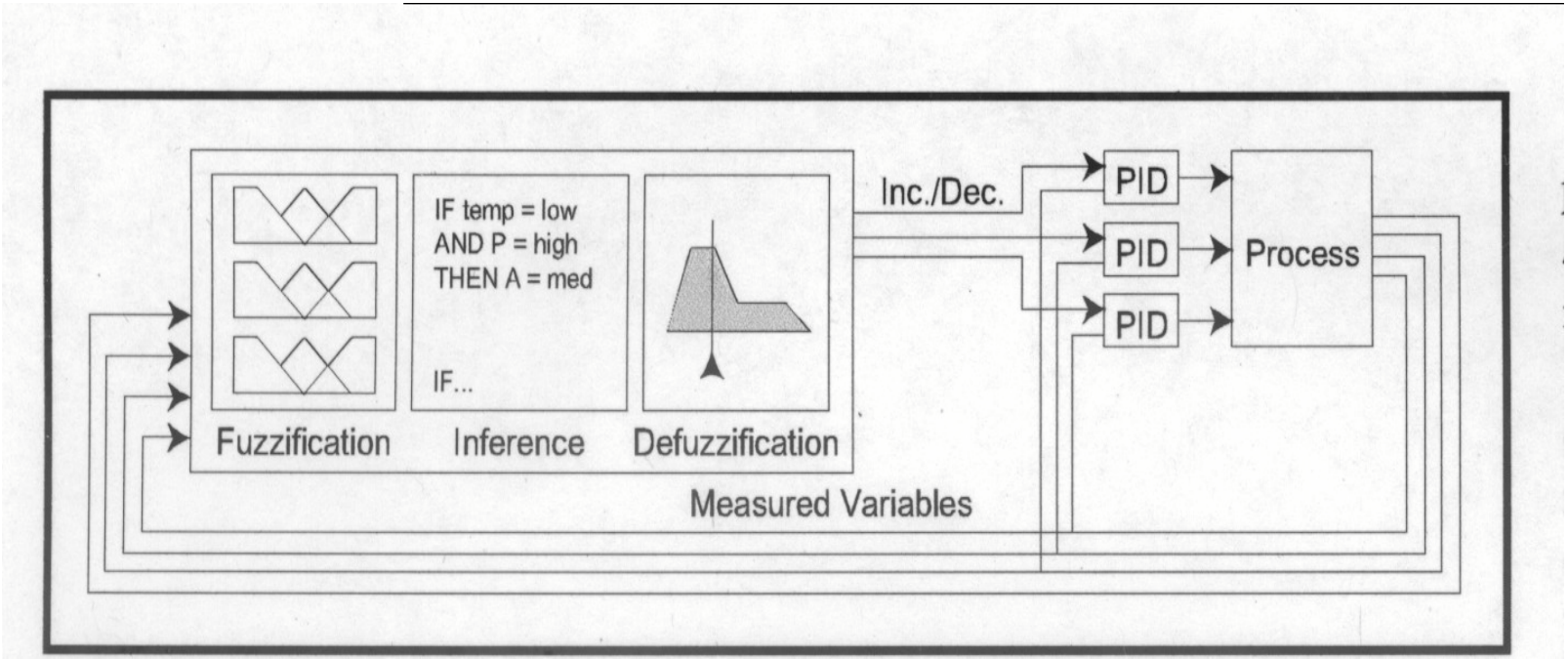
- *Material*
- *Surface finish*
- *Cleanliness*
- *Temperature*
- *Geometry*

ELECTRICAL, OTHER

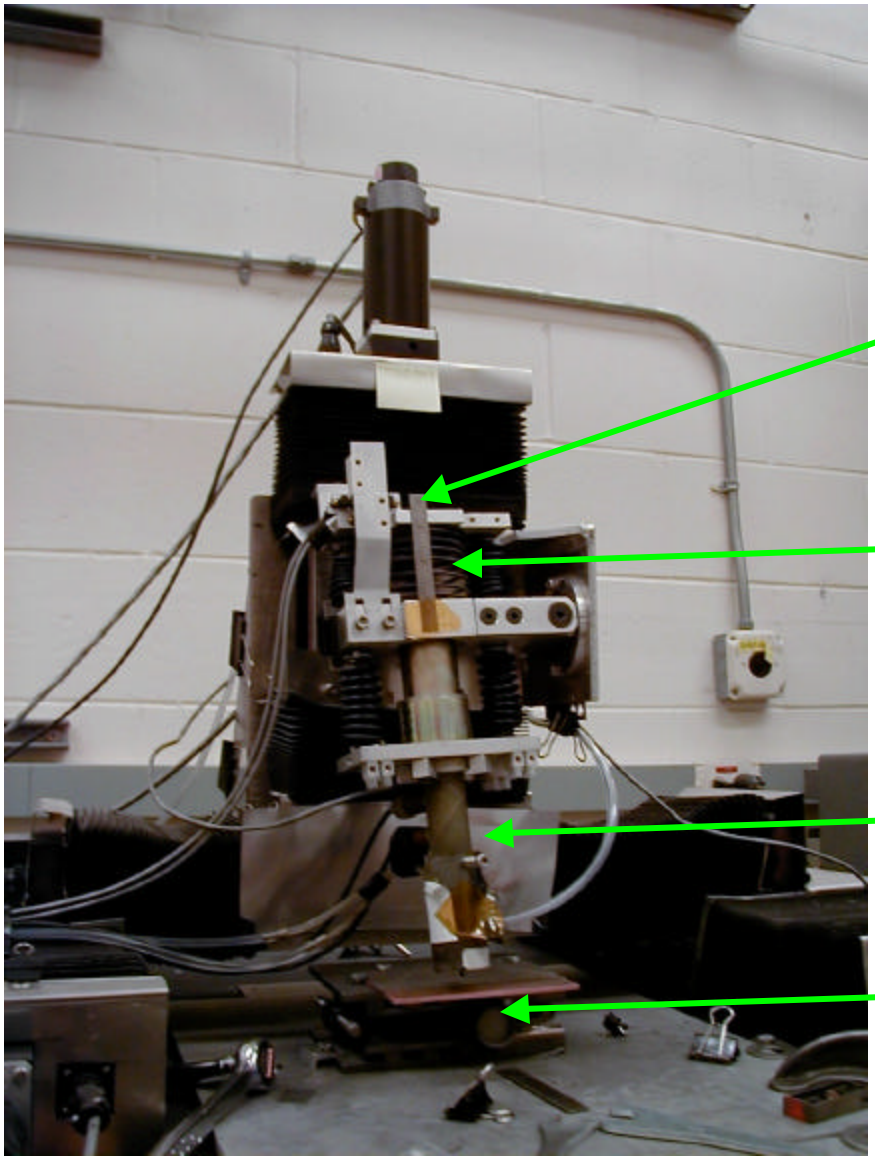
- *Spark energy*
- *Spark frequency*
- *Voltage*
- *Capacitance*
- *Inductance*
- *Spark duration*
- *Sparking time/unit area*
- *Peak current*
- *Rise time*

Fuzzy Logic Controls - being developed to maintain optimum deposition parameters using multivariable inputs.

- voltage - amperage - speed of electrode
- pulse rate - contact force - capacitance, etc.



Options for Placement of Force/Position Sensors



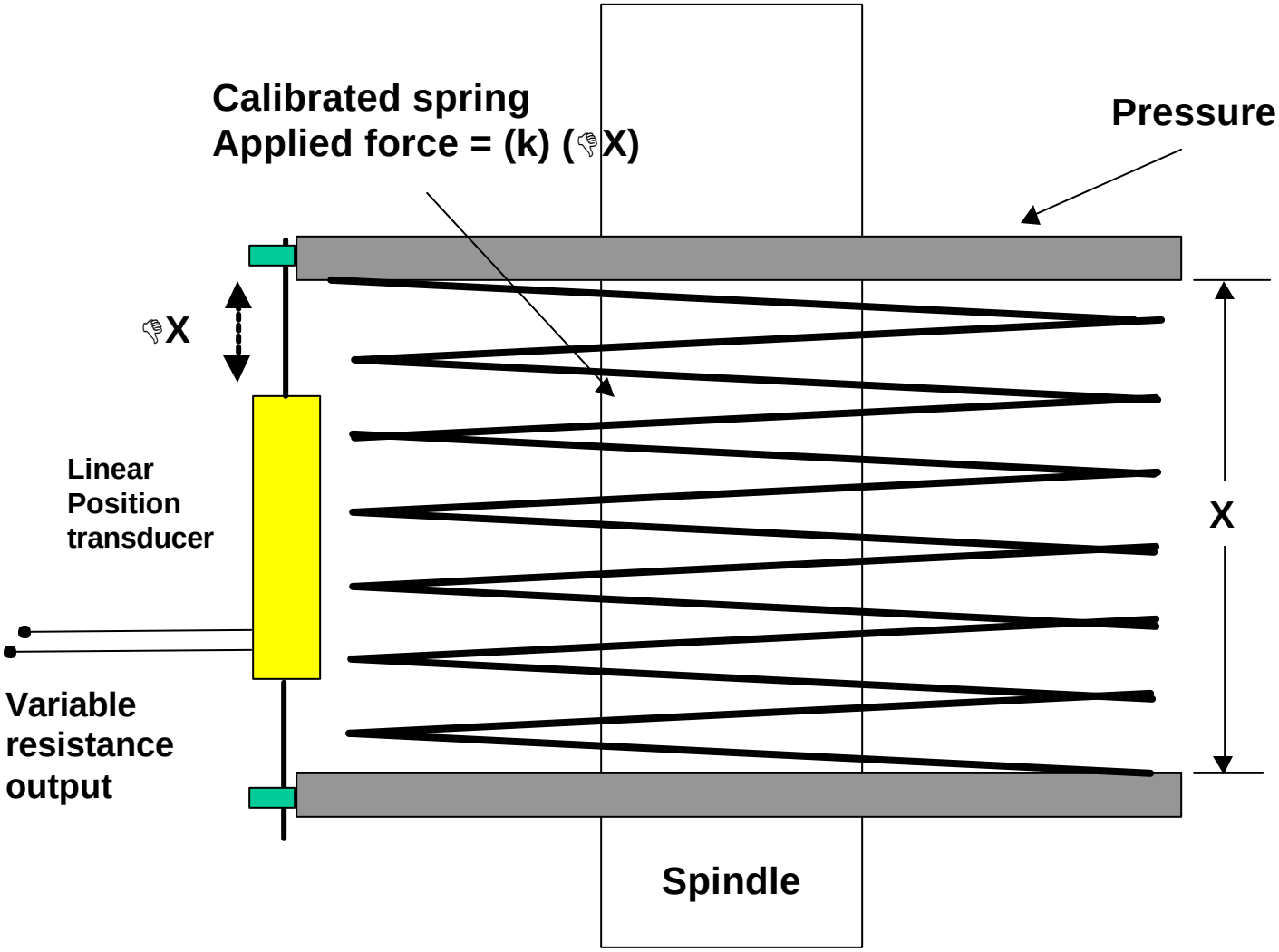
Position/displacement sensor

Load cell on hold-down adjustment

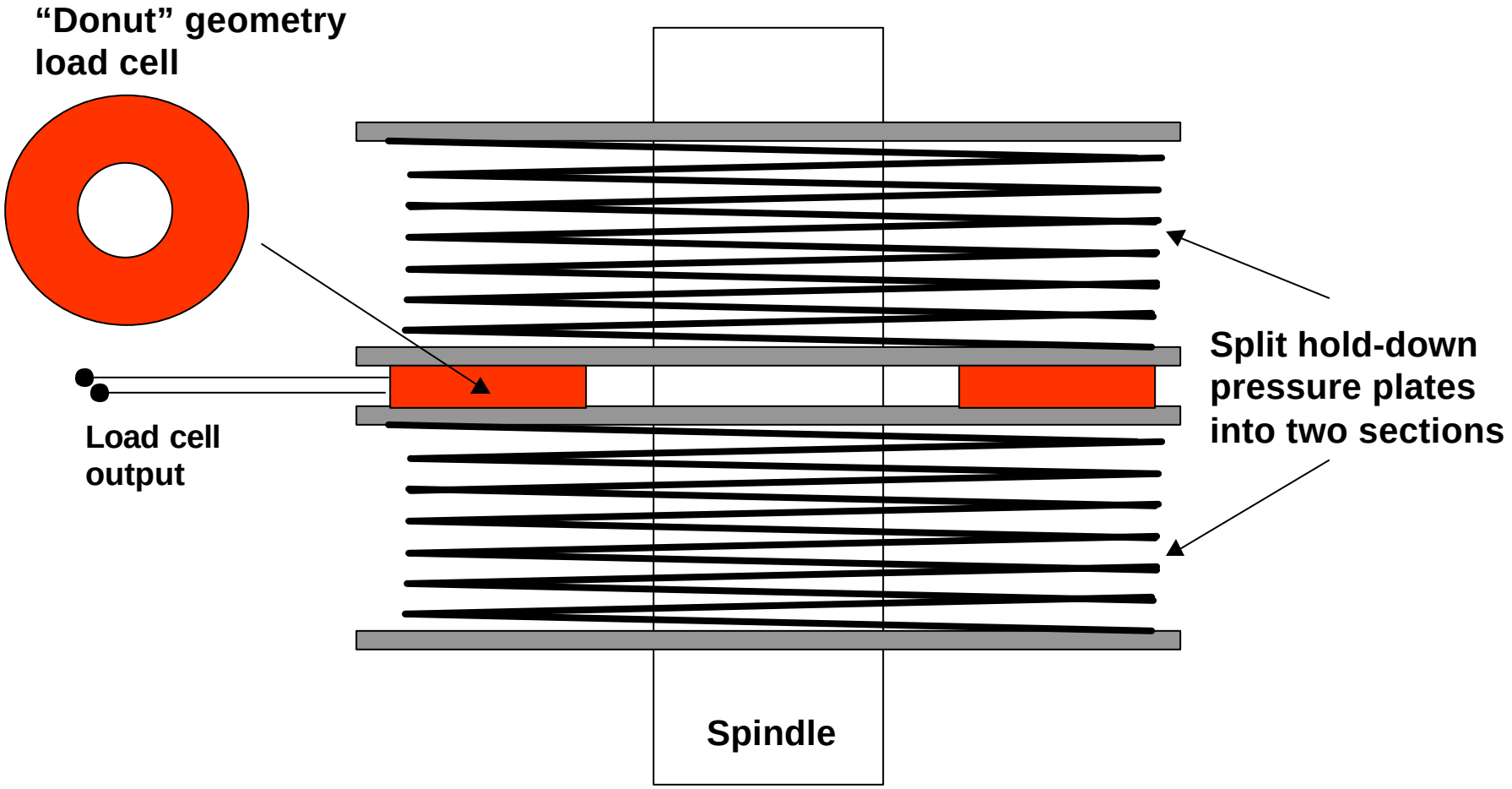
Strain gauge on shaft
(requires slip rings or wireless link)

Load cell under part

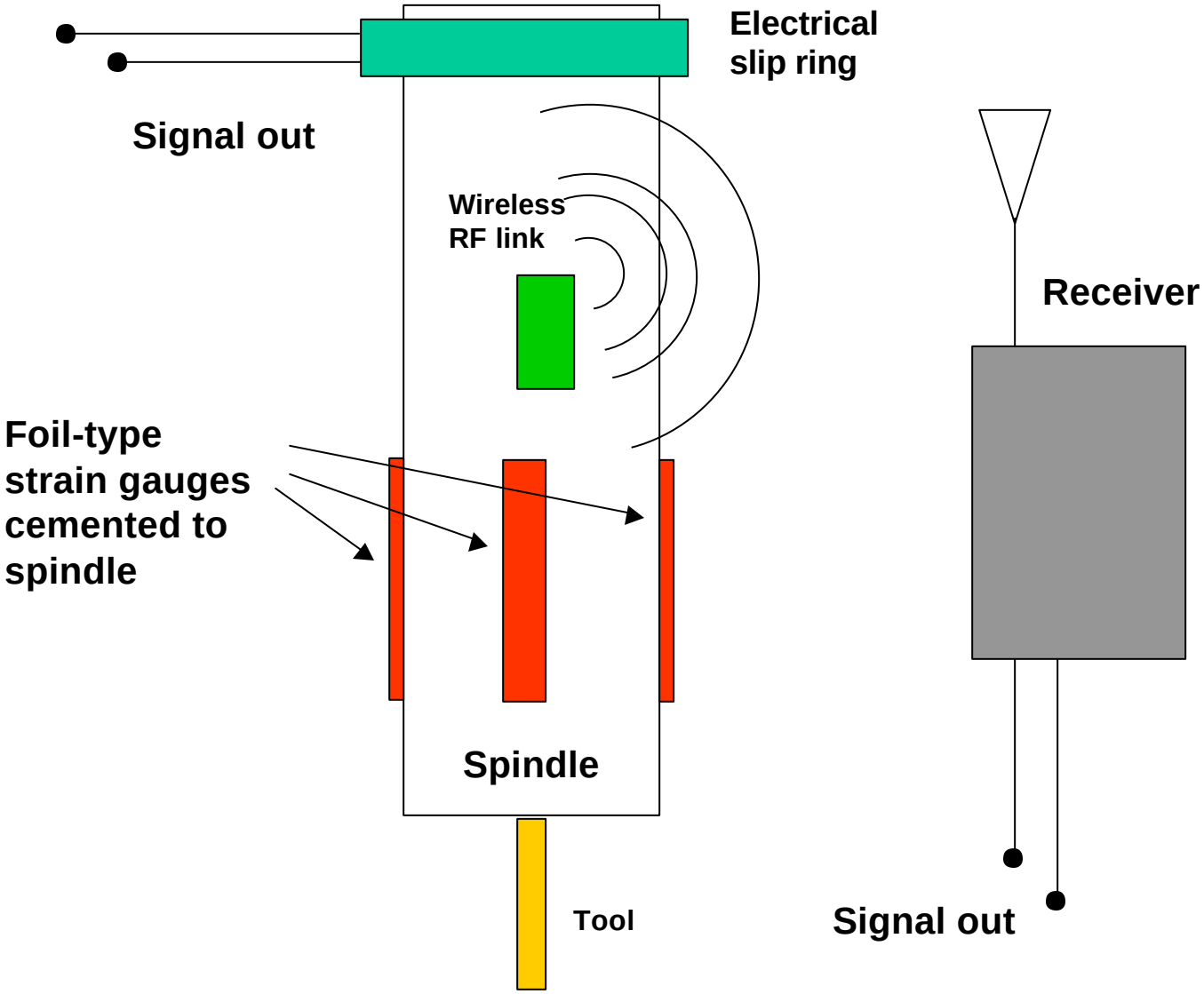
Position/Displacement Sensor



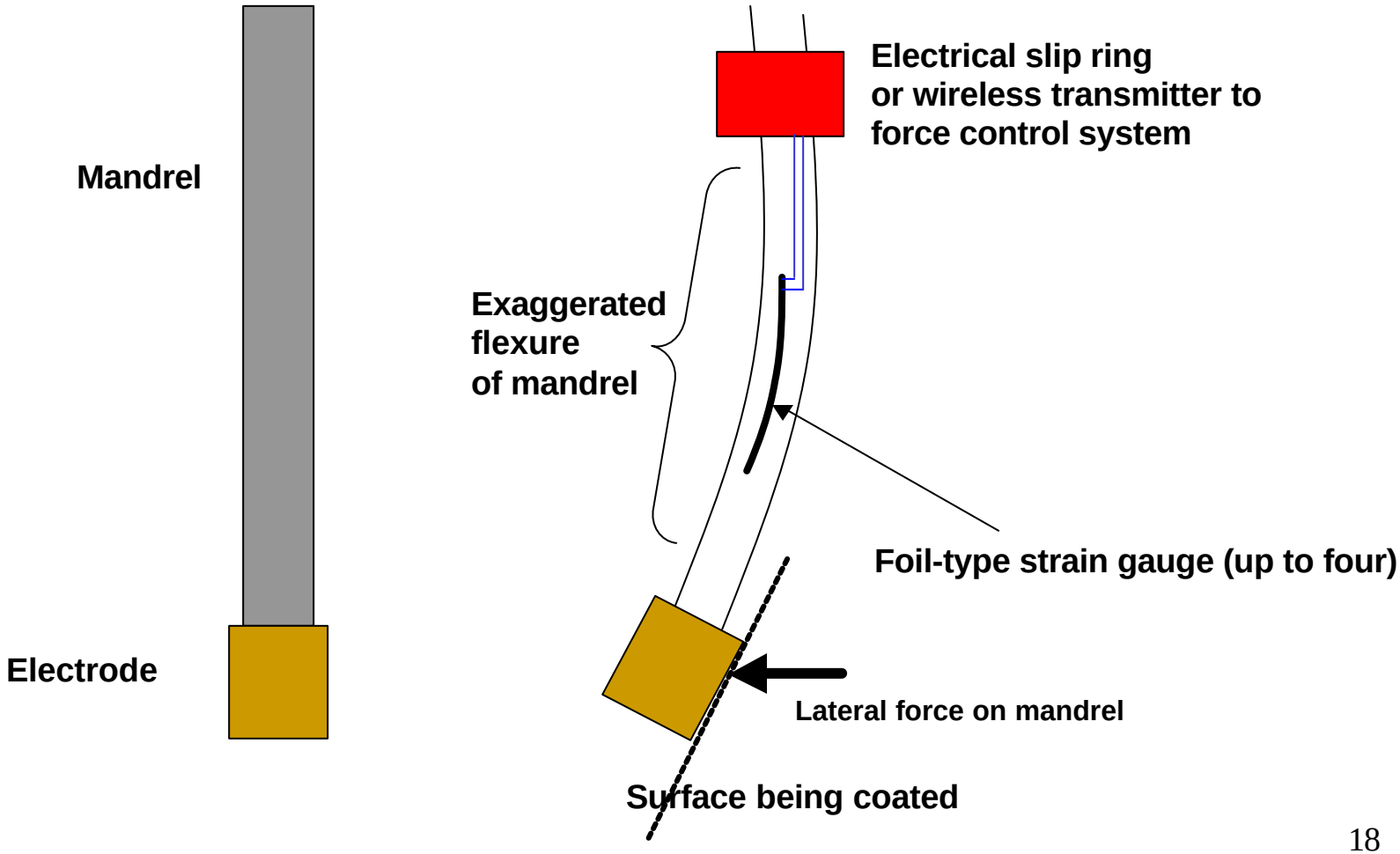
Load Cell on Hold-Down Adjustment for Single Axis Force Control



Concept - Strain Gauge on Shaft
(for monitoring axial and/or 3-D forces on part)



Sensor Geometry for Monitoring Electrode Side Loading



ALTERNATIVE to 3-D SENSORS

A concept to monitor the power supply current passing through (current/voltage/power level) that varies with the contact force of the electrode is being investigated for suitability for use as a method to control the contact force at an optimum level.

Examples of PNNL Miniaturization of Sensors

FY 00 PROGRAM PLAN

- **Complete Tri-Service survey, select representative NLOS geometries**
- **Select baseline materials for focused development**
- **Complete test protocols, start tests**
- **Perform wave form characterization studies**
- **Perform coating properties vs. parameter evaluations**
- **Start sensor and process control development**
- **Make GO/NO GO decision for remainder of program**

FY 01 PROGRAM PLAN

- **Continue testing**
- **Continue parameters vs. coating property evaluations, including coating NLOS surfaces**
- **Continue sensor and process control development**
- **Start fabrication of prototype equipment for NLOS coating**
- **Make Go/No Go decision for remainder of program**

FY 02 PROGRAM PLAN

- **Complete integration of sensors and process controls**
- **Finish fabrication of prototype ESD equipment, demonstrate on NLOS surfaces, test specimens**
- **Complete tests and analyses of coatings**
- **Complete transition plan**
- **Create final report**

DELIVERABLES

1. **Working prototype of ESD system for NLOS surface coatings**

2. **New basic information and understanding of ESD process principles.**

3. **Possible invention/patent disclosure.**

4. **Peer reviewed article.**

5. **Technology deployment plan.**

6. **Test protocols**

7. **Annual Reports**

TRANSITION PLAN

- **Obtain ESTCP funding for LOS/NLOS demonstration/ validation program; qualify ESD coatings as replacement for hard Cr plating**

- **Deploy technology to selected DoD repair depots**

- **Develop plan for full deployment of technology to shops, field, depots, OEMs, shipboard, and for specification development.**

- **Coordinate and work with Hard Chrome Alternatives Team, Joint Group on Pollution Prevention and Propulsion Environmental Working Group, publish on HCAT Home Page**

ESTCP Thoughts

Potential ESTCP partners want to see guidance on coating selection for their applications, specifications, qualified materials and application procedures for DOD uses, fatigue, corrosion and wear data for DoD materials and applications

ESD offers a reduction in chrome use, a potential readiness improvement, eliminates hexavalent chrome from the application process, and offers potential cost savings in certain applications (Small repairs to otherwise serviceable items). Masking of non-repaired areas is not required. Heat treatment for the prevention of hydrogen embrittlement is not required

ESTCP Team will need depot partners